Optical and Photonic Glasses

Lecture 26:

Optical Amplification in Optical Fiber Systems

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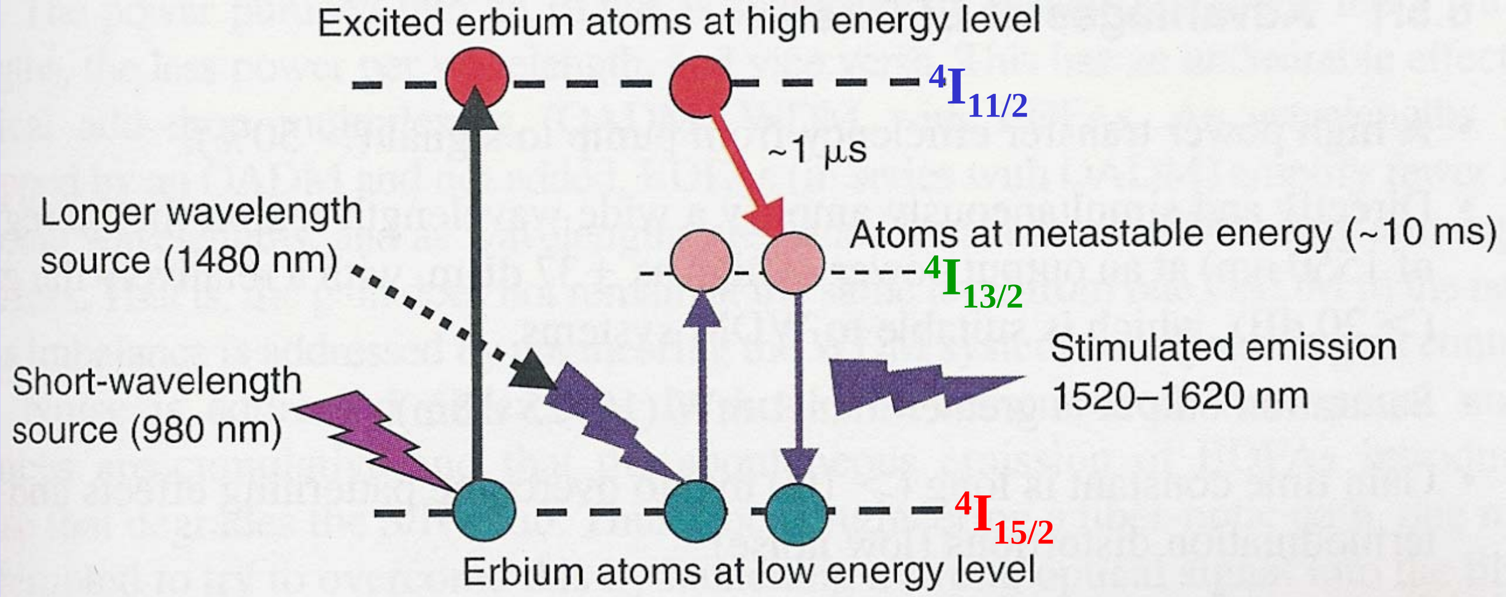
Optical amplification in fiberoptics systems

An attractive amplifier in fiberoptic communications is the all-optical **Erbium Doped Fiber Amplifier** (EDFA), particularly in DWDM systems. The EDFA is a fiber segment a few meters long, doped with Er (and usually co-doped with Al and Ge). The two most convenient excitation wavelengths are 980 nm (3-level system) and 1480 nm (quasi two-level system). When the EDFA fiber is pumped @ 980 nm to the high energy level, after ~ 1 μs the excited Er^{3+} ions fall to the metastable level; if they are triggered by the weakened signal @ ~ 1550 nm (~ ps light pulses), they drop to the ground level and emit light at the triggering wavelength, by *stimulated* emission. If not triggered, the Er^{3+} ions decay by *spontaneous* emission after ~ 10 ms (spontaneous emission lifetime), emitting light @ ~ 1550 nm, which may add to the system noise by ASE.

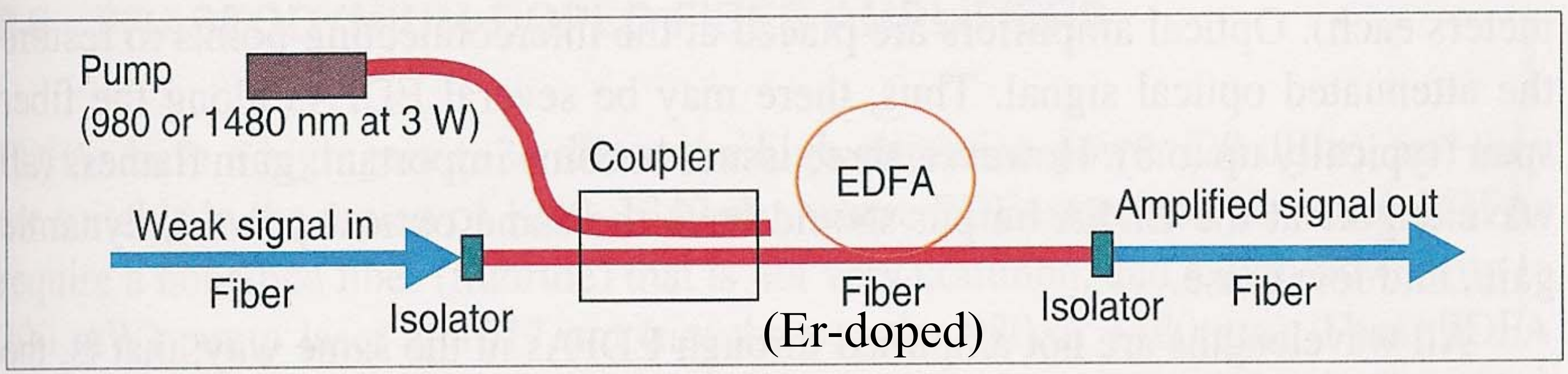


Principles of spontaneous emission of erbium; only the two lowest levels are shown.

(Adapted from: *Introduction to DWDM Technology*, S.V. Kartalopoulos, IEEE Press, 2000)

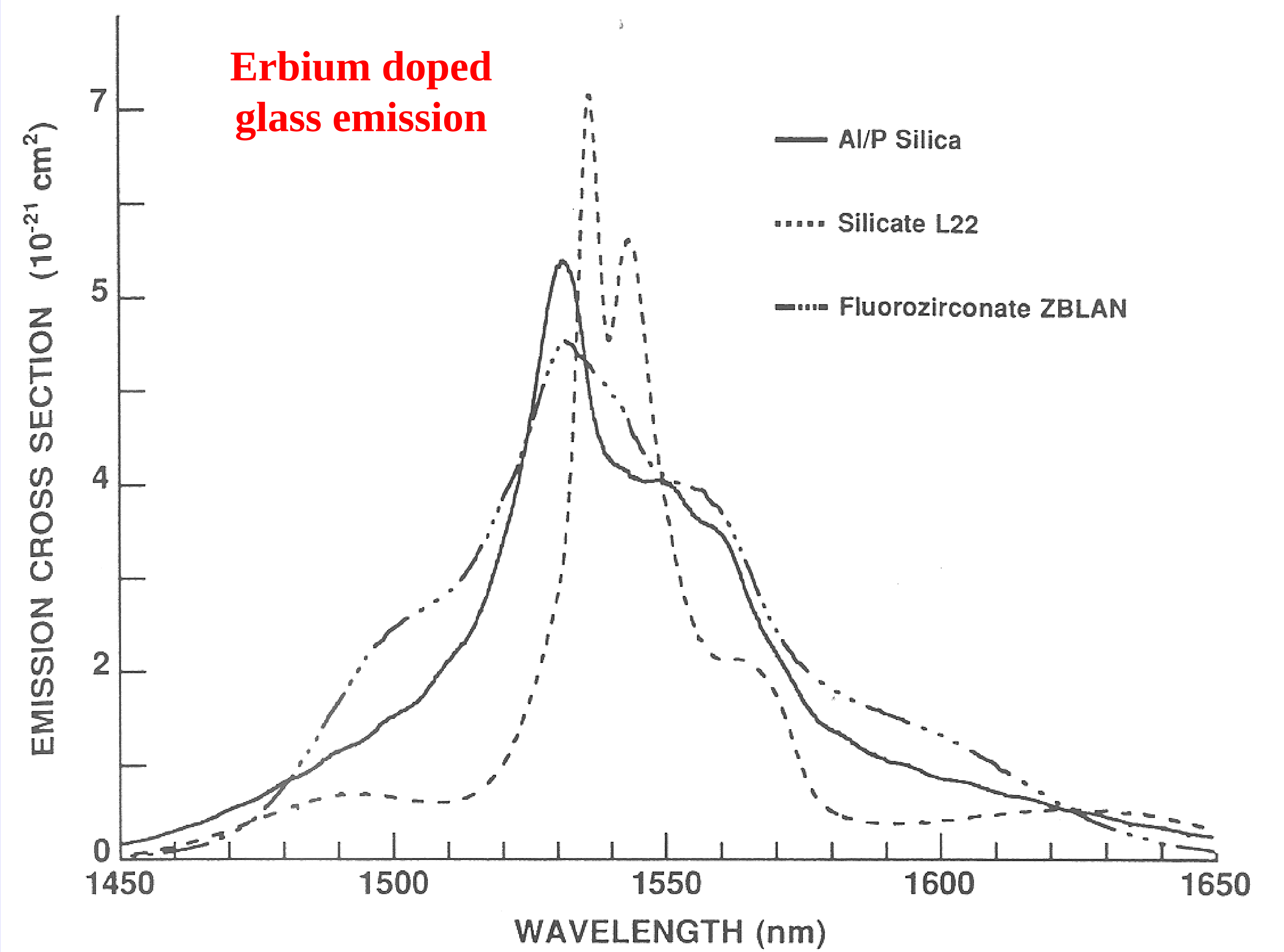
The **EDFA** amplifier consists of a coupling device, an erbium-doped fiber and two optical isolators. The incoming fiber (carrying a weakened signal) is connected to the doped fiber via the isolator, which suppresses light reflections into the incoming fiber. The isolator at the output of the EDFA suppresses reflections from the out going fiber. The EDFA is pumped by a laser at 980 nm or 1480 nm, whose light is coupled to the EDFA and excites the Er^{3+} ions in the doped fiber. In multimode EDFA fibers, pumping can be done through the cladding by means of inexpensive LED pumps.

In a DWDM system, the signal actually contains a series of discrete wavelengths in the 1520-1620 nm range and there are C-band EDFA's, which perform better within the C band (1520-1565 nm) and L-band EDFA's, which perform better in the L-band (1565-1620 nm).

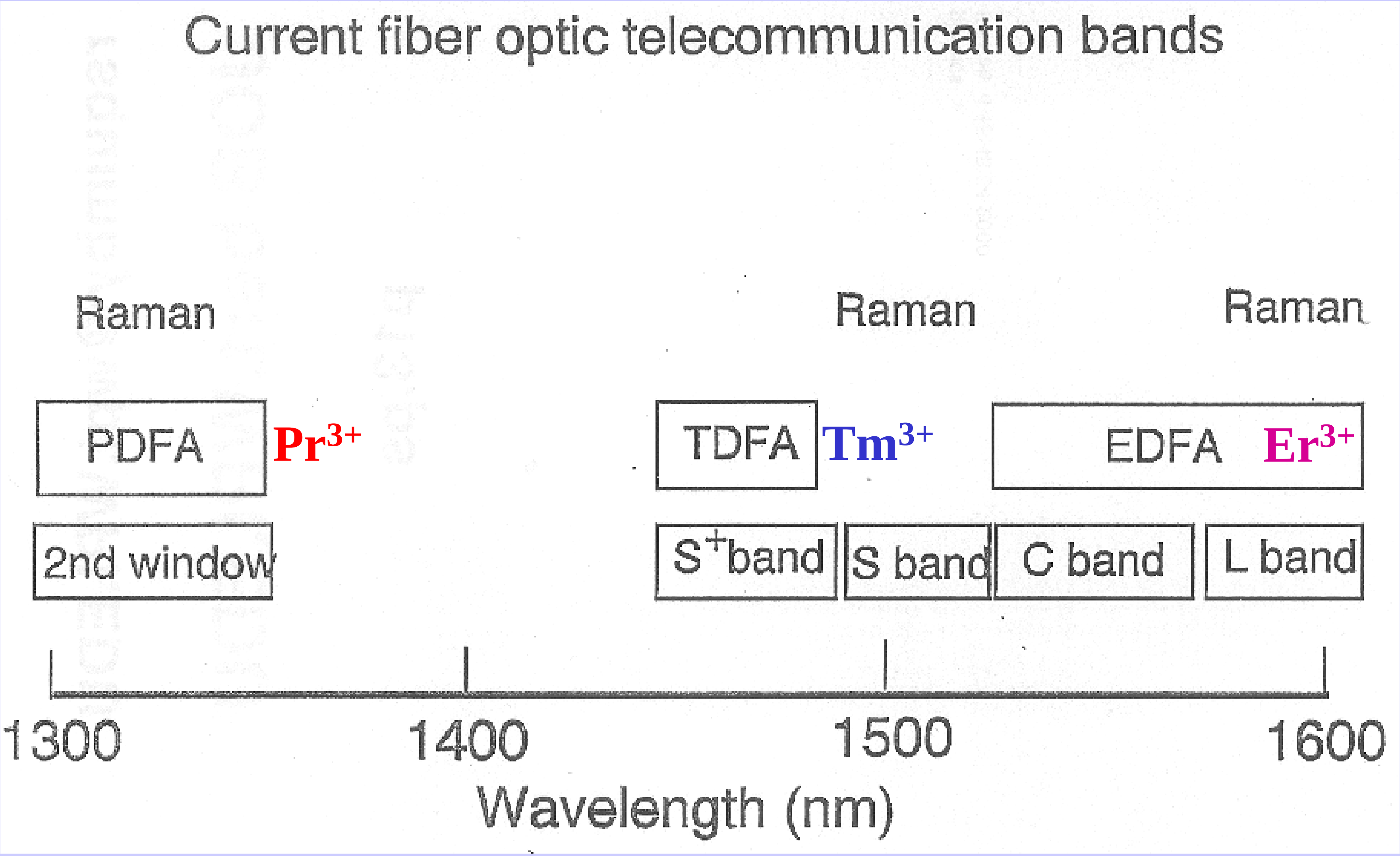


An EDFA amplifier consists of an erbium-doped silica fiber, an optical pump, a coupler, and isolators at both ends.

(Adapted from: *Introduction to DWDM Technology*, S.V. Kartalopoulos, IEEE Press, 2000)



(Adapted from Miniscalco, in: *Rare Earth Doped Fiber Lasers and Amplifiers*, ed. M.J.F. Digonnet, Marcel Dekker, 1993)

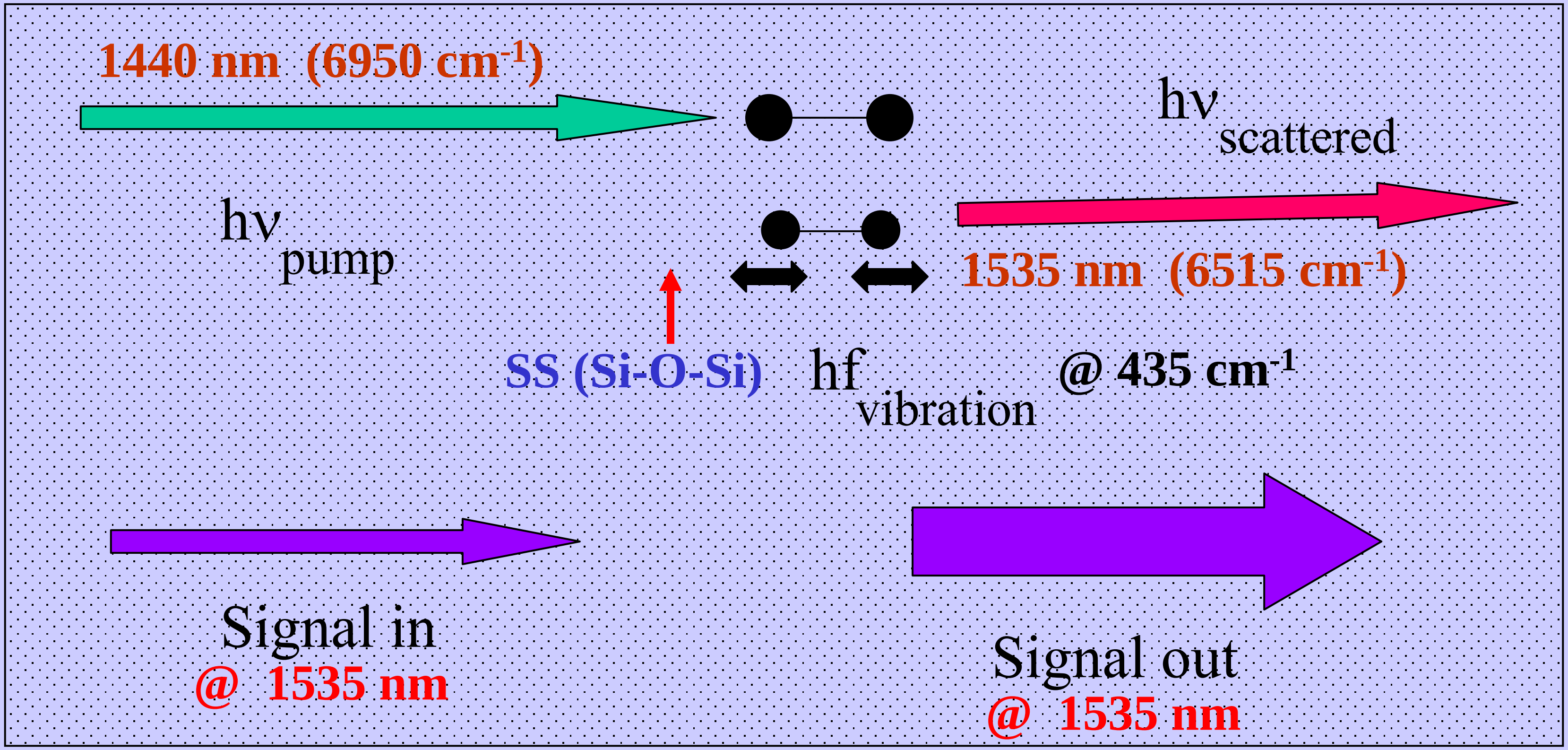


(Adapted from: *Nanophotonics – the emergence of a new paradigm*, R.S. Quimby, on internet)

Raman fiber amplifier

amplification by stimulated Raman scattering (SRS)

non-linear process: high pump power needed (~ 1 W) over several km of undoped fiber

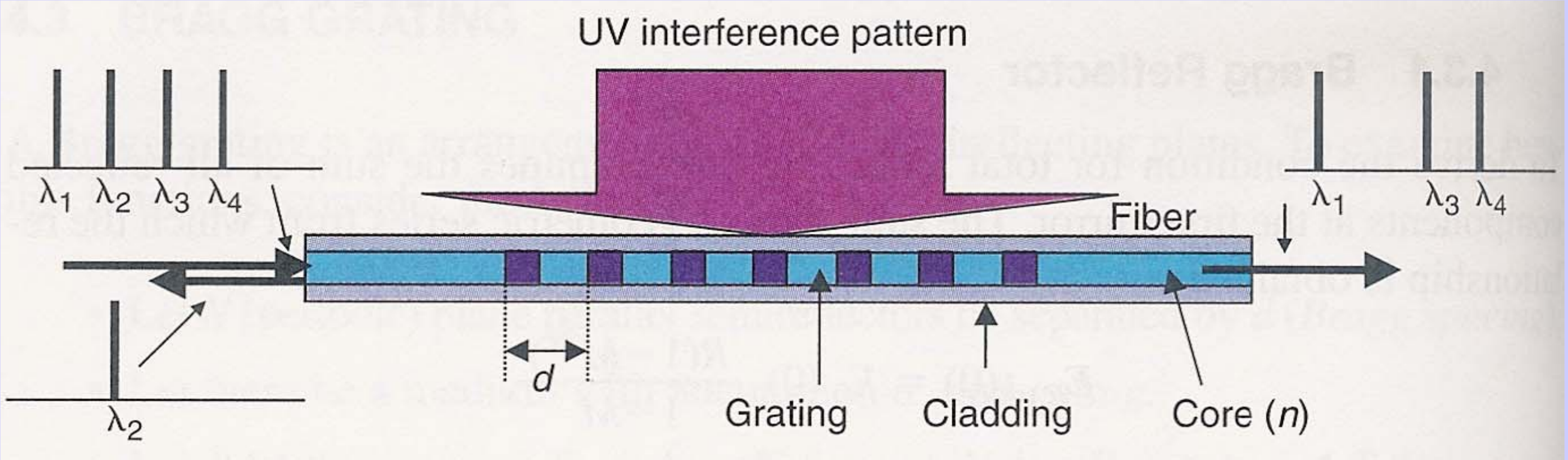


(Adapted from: *Nanophotonics – the emergence of a new paradigm*, R.S. Quimby, on internet)

Special fibers and fiberoptic structures

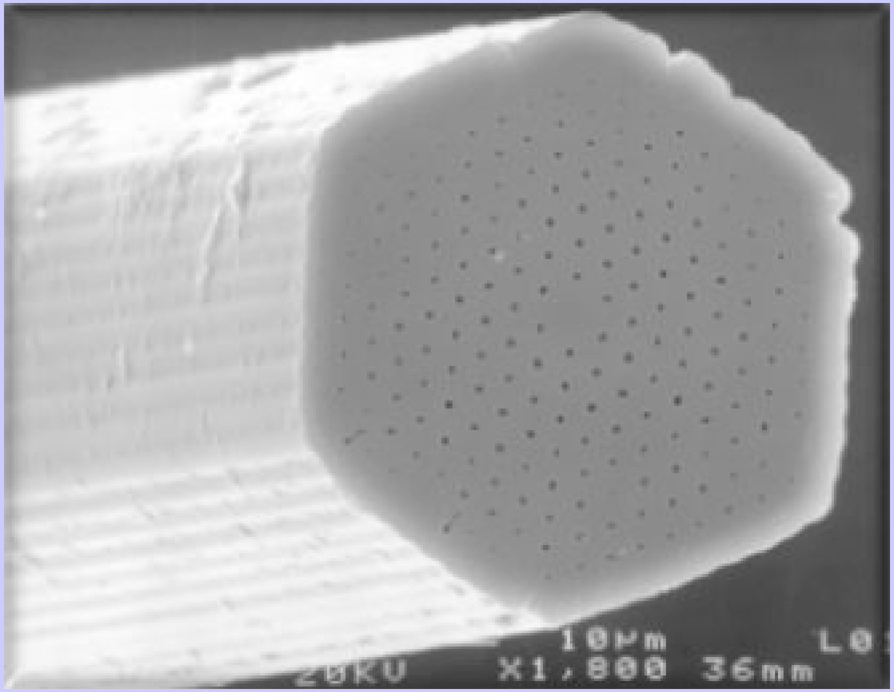
A **fiber Bragg grating** is a fiber segment whose refractive index varies periodically along its length, emulating a Bragg structure. This can be achieved by exposing the germanosilicate core of the optical fiber to an intense UV interference pattern which has the same periodicity as the grating to be formed, leading to permanent variations in the fiber refractive index due to the formation of structural defects. The figure below schematically shows a "in-fiber Bragg grating", incorporated in-line with a transmitting fiber.

The UV source is usually an excimer laser operating in the 157-351 nm range. Absorption by the fiber peaks at 240 nm. A pulsed laser (e.g. KrF excimer laser @ 248 nm) may create a grating pattern in a fiber with a single high energy shot, as the fiber is drawn. The fiber gratings may be used as filters, optical couplers, demultiplexers, etc.



(Adapted from: *Introduction to DWDM Technology*, S.V. Kartalopoulos, IEEE Press, 2000)

Photonic crystal (PC) fibers (also called “holey” fibers)
special type of photonic bandgap structures with holes along the fiber axis, defining a 2-D hexagonal periodic pattern

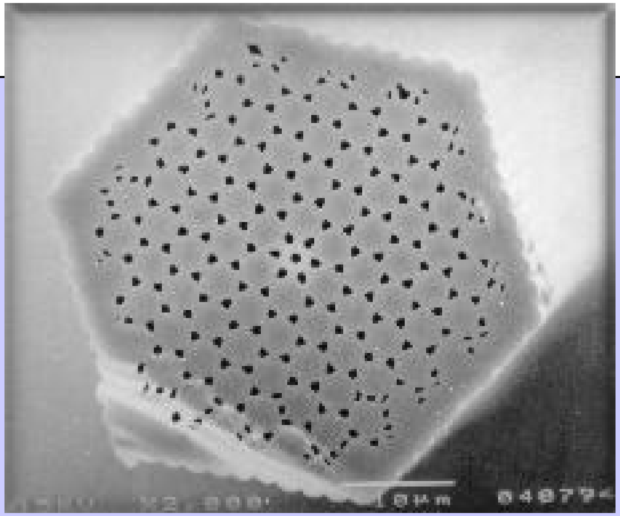


after Birks, Opt. Lett. **22**, 961 (1997)

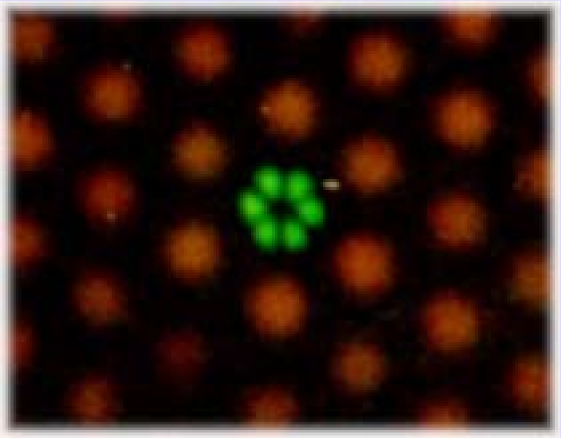
- “holey” fiber / **solid core**
- stack rods & tubes, draw down into fiber
- variety of patterns, hole width/spacing ratio
- guiding by:
  - effective index (TIR)

(Adapted from: *Nanophotonics: the emergence of a new paradigm*, R.S. Quimby, on internet)

PC fiber with hollow core



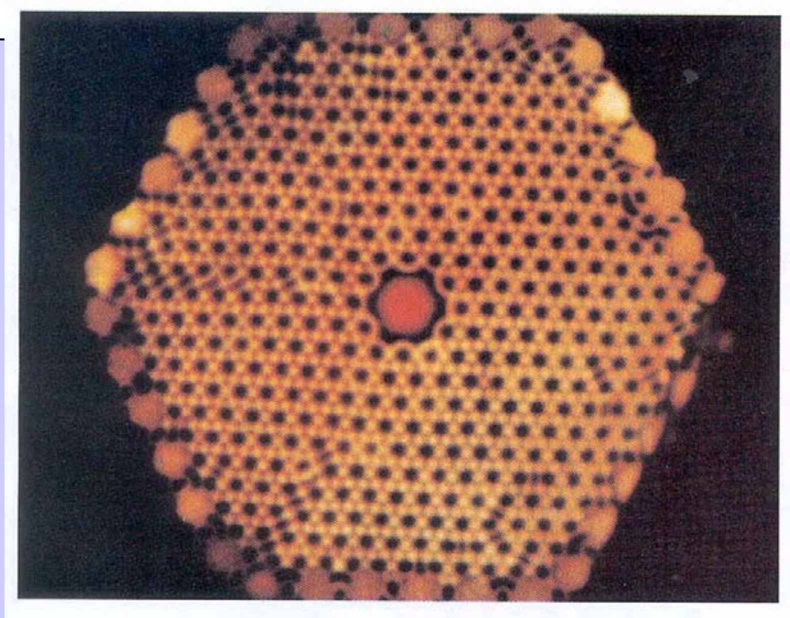
after Knight, Science **282**, 1476 (1998)



- air core: the “holey” grail
- confinement by PBG (core is a defect)
- first demonstrated in honeycomb structure
- propagating mode takes on symmetry of photonic crystal

(Adapted from: *Nanophotonics – the emergence of a new paradigm*, R.S. Quimby, on internet)

PC fiber with large hollow core



after Knight, *Optics & Photonics News,* March 2002

- high power transmission without nonlinear optical effects (light mostly in air)
- losses now ~1 dB/m (can be lower than in index-guiding fiber, in principle)
- small material dispersion

(Adapted from: *Nanophotonics – the emergence of a new paradigm*, R.S. Quimby, on internet)